US HL-LHC Accelerator Upgrade Project

Quality Assurance Plan

Prepared by:
Jamie Blowers, Project QA Manager, Technical Division - Fermilab

Reviewed by:
Ruben Carcagno, Deputy Project Manager, Technical Division - Fermilab

Approved by:
(approval records are kept in us-hilumi-docdb.fnal.gov)
Giorgio Apollinari, Project Manager, Technical Division - Fermilab

Revision History

Revision	Date	Section No.	Revision Description
V1	7/18/17	All	Initial Release
V2	11/20/18	3 5.2.3 3.1.1, 5.1.4, 5.4.1, 6.2 5.1.4 5.2 6.1.1	Added references to BNL and LBNL QA Plans; changed TD to APS-TD Defined which deliverables are Configuration Items Added reference to AUP Integration Plan Changed reference from *design authority* to *design-responsible organization* Removed details and added reference to the Configuration Management Plan Added section on Significant NCRs

TABLE OF CONTENTS

1. Purpose

The purpose of the Large Hadron Collider High Luminosity Accelerator Upgrade Project (HL-LHC AUP) is to design, build, test, and deliver to CERN, components for an upgrade to the LHC. Fermilab is the lead lab, working with Brookhaven National Laboratory (BNL), and Lawrence Berkley National Laboratory (LBNL), to provide the deliverables to CERN, as defined in Statements of Work and Work Breakdown Structures[1].

The purpose of this Quality Assurance Plan is to describe the policies and procedures for assuring the work related to the HL-LHC AUP (hereafter referred to as "the Project"). This document is formatted using the guidelines defined by ISO9001. Relations to the DOE O 414.1x Quality Assurance Criteria are listed in the headings of each subsection.

2. Scope

The descriptions and requirements in this plan are applicable to all Project activities (i.e. Fermilab, all collaborating institutions, and their subcontractors). Scope includes the design, fabrication, testing, and delivery of LQXFA and LQXFB magnet cryoassemblies (MQXF magnets), and Radio Frequency Dipole (RFD) dressed crab cavities.

This document is written to describe the Project's overall approach to quality, as well as to describe the specifics of how the work is being performed at Fermilab. To make it easier for the collaborating institutions to understand the requirements they are to adopt, section 7 has been added to explicitly list their requirements (like the CRD in a DOE order).

3. Quality Management System (Criterion 1)

The QA strategy of the Project is to leverage the quality systems, tools, and personnel knowledge and experience at each lab. To this end, the Project requires a formal (i.e. documented) quality system and plans be in place and used at each lab, which cover the scope of their work. In addition, certain project-specific procedures will be instituted (e.g. reviews), as well as integration of various QA topics between the labs (e.g. communicating of NCRs). CERN-specific requirements have been incorporated into this document.

All quality controls are applied using a graded approach, i.e. using a level of rigor which is commensurate with the risk. In general, each lab is responsible for instituting the "graded approach" in a manner which is already being done at that lab (i.e. leverage the systems already being used).

Fermilab specifics:

Fermilab maintains a formal quality program, which is described in the following documents:

- *Director's Quality Assurance Policy*[2]
- *Fermilab Integrated Quality Assurance Program*[3]

Engineering work at Fermilab is performed per the *Fermilab Engineering Manual*[4].

[1] Available in the HiLumi AUP DocDB site

[2] http://esh-docdb.fnal.gov/cgi-bin/ShowDocument?docid=2572

[3] http://esh-docdb.fnal.gov/cgi-bin/ShowDocument?docid=2469

[4] http://www.fnal.gov/directorate/documents.html

The Applied Physics and Superconducting Technology Division (APS-TD), where the magnet and cavity work will be completed at Fermilab, has maintained a formal quality system for many years. The specifics of the Division system are defined in policy TD-2010 *Quality Management Program*[5].

LBNL specifics:
Work performed by LBNL is performed within the framework of their Quality Program Description document[6], and using the LBNL AUP QA Plan (DocDB #1491[7]).

BNL specifics:
Work performed by BNL is performed within the framework of their Institutional Quality Assurance Program[8], and using the BNL AUP QA Plan (DocDB #945[9]).

3.1. Information Approval and Issue (Criterion 4)

3.1.1. Documents

In order to appropriately control and communicate the correct project information, a system for document and data control must be used. In general, information (in the form of a document or data set) is put under control if it is necessary to ensure that the published version is the most current. Typically, the owner(s) of the document or data determine whether it should be controlled. The principles of document and data control are:

1) Controlled documents and data are reviewed and approved by authorized personnel prior to issue (this also means that controls must be in place to prevent unauthorized changes to controlled information);
2) The location of the most up-to-date version is known and available to the appropriate personnel.

At a minimum, the following documents are placed under document control:

- Project Management documents (i.e. the documents required to meet the DOE O 413 requirements)
- Drawings and Engineering Specifications (e.g. functional, technical, interface)
- Procurement Specifications
- Travelers, work instructions, and operating procedures

Per CERN procedure *Documentation Management in EDMS HL-LHC WP Workspace* (EDMS 1501017[10]), the Project will upload the following documents to the CERN EDMS:

- Functional/Engineering Specifications
- Interface Specifications
- Manufacturing and Inspection Plans (MIPs, per EDMS 1563887[11])

[5] http://www-tdserver1.fnal.gov/tdweb/hq/policies/2010.pdf
[6] https://commons.lbl.gov/download/attachments/77332681/PUB+3111+OQMP.pdf
[7] https://us-hilumi-docdbcert.fnal.gov/cgi-bin/cert/ShowDocument?docid=1491
[8] https://sbms.bnl.gov/SBMSearch/ProgDesc/QAP/QAP_PD.cfm
[9] https://us-hilumi-docdbcert.fnal.gov/cgi-bin/cert/ShowDocument?docid=945
[10] https://edms.cern.ch/document/1501017/
[11] https://edms.cern.ch/document/1563887/

The Project uses DocDB to manage internal documents, the CERN EDMS system to manage all document deliverables, and the CERN MTF system to manage data deliverables associated with the fabrication and testing of the hardware.

Each lab will utilize their own Engineering Data Management System (EDMS) and/or Product Data Management (PDM) system to manage design data and document control (for documents specific to their scope of work).

Additional details regarding document control can be found in the AUP Integration Plan (DocDB #1166[12]).

Fermilab specifics

Fermilab uses Siemens Teamcenter to control all engineering-related documents and data, and the Vector electronic traveler system to manage all travelers.

3.1.2. Records

Quality records provide objective evidence of accomplished work, and as such are an important part of the Project. To the extent practical, records will be made available in electronic format via a structured system, so as to make them readily accessible to Project personnel, collaborating institutions, and to the customer. BNL, LBNL, and other collaborating institution staff have been given access to the Fermilab DocDB, Teamcenter, and Vector systems in order to have direct access to Fermilab documents and data.

At a minimum, the following records are maintained:

- Records of reviews, including presentations and reports
- Procurement records, including purchase orders and associated specifications
- Design records, including records of design basis and as-built drawings
- Production records, including those from suppliers
- Records of testing, including travelers, checklists and reports

Deliverables that include records and data will be provided to CERN, per CERN *Records Management Procedure* (EDMS 1518361[13]). At a minimum, these will include all drawings, magnet and cavity performance testing results, and a listing of Nonconformance Reports (NCRs) associated with each magnet cryoassembly and dressed cavity.

4. Resources (Criterion 2)

Each Lab Director, along with the head of the Applied Physics and Superconducting Technology Division (FNAL) and the Senior Team Leads (BNL, LBNL, collaborating institutions) are responsible for providing the necessary resources to be able to safely complete the work of the Project. These resources include the appropriate staff, competent in the work they are performing, and the necessary infrastructure and work environment to allow the work to be done safely and to meet all quality requirements.

Staff are considered competent through a combination of education, formal training and procedures, past work experiences, and on-the-job training.

[12] https://us-hilumi-docdbcert.fnal.gov/cgi-bin/cert/ShowDocument?docid=1166

[13] https://edms.cern.ch/document/1518361/

5. Product Realization

It is the policy of the Project that the appropriate systems are used to ensure that the end-product meets the defined requirements. In addition, the Project follows the CERN *HL-LHC Quality Assurance Management Plan* (EDMS 1513591[14]), and associated procedures.

The major systems in use are:

1) Design;
2) Configuration Management
3) Procurement;
4) Production;
5) Inspection and testing;

All Fermilab employees and contractors working on the Project have the authority, and responsibility, to stop work if a safety or quality issue is discovered. In that event, the Responsible Authority for the work in question is responsible for addressing the concern prior to work recommencing.

5.1. Design (Criterion 6)

The ultimate deliverables for the design process are the detailed drawings and specifications needed to construct and transport the necessary hardware deliverables. These typically come in the form of drawings and specification documents. The quality of the designs are controlled primarily through having the appropriate personnel conduct their work using standardized systems, and reviewing the work as appropriate.

5.1.1. Design Input

The functional requirements of the components are defined and documented in *Functional Requirements Specifications*, and these serve as the primary inputs into the design process. The FRSs may be authored by Project staff, but they are reviewed and approved by CERN, and accepted by the Project. FRSs are stored in the CERN EDMS database[15].

5.1.2. Design Reviews

Reviews of design work are conducted throughout the project. These reviews may be informal, or very formal. They could be part of an overall project review, or they could apply to a very specific piece of equipment. Records of informal reviews may not be maintained, but records for formal reviews are maintained and published.

Reviews are conducted per the Project Design Review Plan[16], and meet the requirements defined in the CERN procedure *Technical Reviews Process* (EDMS 1506731[17]).

5.1.3. Interfaces

Interfaces between subsystems must be properly understood and controlled to ensure the desired outcome of the Project. The Project is organized using a Work Breakdown Structure, and the interfaces between work packages have been identified and documented in an Interface Control Matrix[18]. Where an interface

[14] https://edms.cern.ch/document/1513591/
[15] https://edms.cern.ch/project/CERN-0000096381
[16] https://us-hilumi-docdb.fnal.gov:440/cgi-bin/ShowDocument?docid=170
[17] https://edms.cern.ch/document/1506731/
[18] https://us-hilumi-docdb.fnal.gov:440/cgi-bin/ShowDocument?docid=219

has been identified, an interface specification shall be written, reviewed by the appropriate individuals, and approved. The interfaces with CERN systems are within the scope of this system.

Once an interface specification is approved, changes are controlled using the Configuration Management system.

5.1.4. Model and Drawing Control

Project design work is done through the development of 3-D models and 2-D drawings using a standard CAD system (Siemens NX at Fermilab, CREO at BNL and LBNL), and the data are controlled using an Engineering Data Management System (Teamcenter at Fermilab, Windchill at BNL and LBNL). Every attempt is made to develop the 2-D drawings using an internationally recognized drawing standard (e.g. ASME Y14.5M). All drawings for official use go through a formal release process.

In addition, the Project will meet the requirements of CERN procedure *Design Process – Creation of Drawings for the HL-LHC* (EDMS 1506718[19]) by uploading models (stp files) and drawings to the CERN Drawing Directory (CDD).

Additional details regarding integrating design data across the various design-responsible organizations can be found in the AUP Integration Plan (DocDB #1166[20]).

5.2. Configuration Management

Configuration management (CM) is the work of maintaining the appropriate level of control over the designs and hardware, with the goal of knowing 1) the designs are properly approved, and changes are properly controlled, and 2) that the hardware is purchased and built to approved designs, and 3) that the hardware is traceable to the exact version of the approved design. The Project's strategy for implementing CM entails defining and approving baselines (technical, cost, schedule), defining and approving hardware designs (drawings, specifications), defining and approving process controls (travelers, work instructions, operating procedures), and controlling changes to all these. In addition, Configuration Items (CIs) have been defined by CERN, and baselining and changes for these are approved through CERN procedure *Configuration Management Process* (EDMS 1511438[21]).

Details of how CM is accomplished for the Project are defined in the Configuration Management Plan (DocDB #1067[22]).

5.3. Procurement (Criterion 7)

The Project conducts all procurement activities such that all applicable ES&H and quality requirements are fulfilled. In general, procurement activities involve the definition of product requirements (i.e. input), the bid and supplier review cycle, awarding of the bid, on-going supplier oversight, and receiving inspection. The QA requirements in this document flow down to suppliers, and are verified using a graded approach. Specifics regarding procurement management for the Project are documented in the Procurement Management Plan[23].

[19] https://edms.cern.ch/document/1506718/
[20] https://us-hilumi-docdbcert.fnal.gov/cgi-bin/cert/ShowDocument?docid=1166
[21] https://edms.cern.ch/document/1511438/
[22] https://us-hilumi-docdbcert.fnal.gov/cgi-bin/cert/ShowDocument?docid=1067
[23] https://us-hilumi-docdb.fnal.gov:440/cgi-bin/ShowDocument?docid=195

5.3.1. Input into the procurement process

Input into the procurement process is critical for success. Procurement specifications that contain errors, ambiguous requirements, or are missing critical information, are likely to result in a wide range of problems and wasted time. As such, the Project requires that specifications be complete and unambiguous, and under document control.

5.3.2. Receiving Inspection

As per the Procurement Management Plan, section 6.13, quality control plans are to be defined as part of the bid creation process, and within the scope of the Procurement Readiness Review. In addition, for procurements defined as Significant, Major, or Critical, the QC Plan shall be a formal document. These procurements are identified in the appendices of the Procurement Management Plan.

5.4. Production (Criterion 5)

The policy of the Project is that production processes be properly planned, appropriately documented and reviewed, and that they be carried out under controlled conditions. Typically, all production is controlled using work instructions and/or 'travelers.' These documents serve to instruct Production personnel on the sequence of work, as well as for in-process inspections. They also provide a record of how the work was completed. Suppliers that are fabricating sufficiently complex components (e.g. cavities) are required to deliver records of their fabrication and testing, along with the hardware they are producing.

All fabrication and testing work performed at Fermilab will be done with the use of travelers in the Vector electronic traveler system[24].

The following depicts the production flow of the magnet cryoassemblies, as found in the Q1/Q3 Cryoassembly Production Plan[25]:

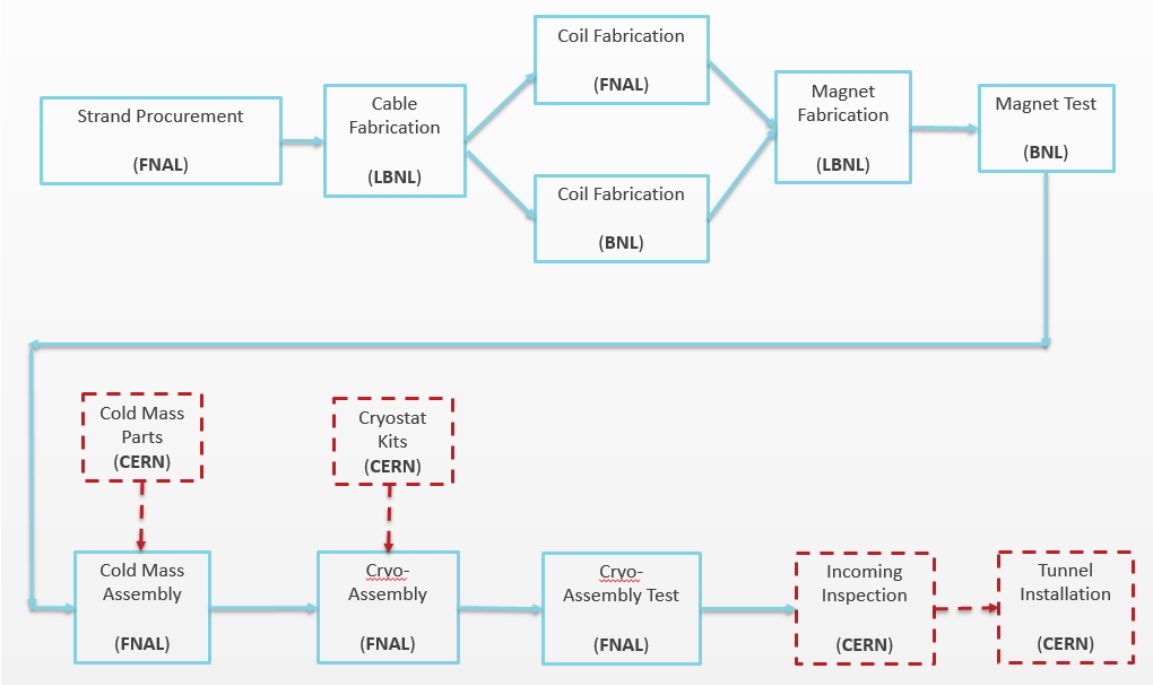

Figure 2 – Q1/Q3 cryoassembly production flow

[24] http://vector.fnal.gov

[25] https://us-hilumi-docdb.fnal.gov:440/cgi-bin/ShowDocument?docid=138

5.4.1. Product Identification & Traceability

The Project requires that systems be used to provide product identification and traceability. These systems must track the materials and subcomponents from procurement, to receiving inspection, to product fabrication/assembly, and to final testing. Components provided by suppliers must also meet these requirements. The systems in use by the Project fulfill the CERN requirements per the CERN document *HL Product Identification and Traceability Process* (EDMS 1511434[26]).

Additional details regarding ID and traceability can be found in the AUP Integration Plan (DocDB #1166[27]).

The systems for ID & Traceability at Fermilab include the Oracle eBusiness Suite (eBS) purchasing system, the TD/QMD "Routing Form" database (covers receiving and receiving inspection), parts kits, and the electronic travelers.

5.5. Inspection & Testing (Criterion 8)

Throughout the product realization life-cycle, inspection and testing steps are incorporated to ensure that products meet the defined requirements. This includes incoming inspection, in-process inspection, and complete assembly testing. Records of these inspections and tests are maintained. This work entails determining the measurements to be taken, the accuracy required, and the selection of the most appropriate measurement devices.

5.5.1. Control of Monitoring and Measuring Devices

Devices used to monitor or otherwise verify product quality are appropriately maintained, per the following considerations:

- Identifying all test equipment that can affect product quality, and calibrate or verify at prescribed intervals, or prior to use, against measurement standards traceable to international or national measurement standards. Where no such standards exist, the basis used for calibration or verification is recorded;
- Identifying test equipment calibration status appropriately;
- Ensuring that the environmental conditions are suitable for the tests being carried out;
- Ensuring that the handling, preservation, and storage of test equipment is such that the accuracy and fitness for use is maintained. This includes preventing adjustments to test equipment that would invalidate the calibration setting;
- Assessing and documenting the validity of previous test results when test equipment is found to be out of calibration.

6. Measurement, Analysis and Improvement (Criterion 3)

As stated in previous sections, many feedback systems are in place in the Project. These systems help to ensure that defined requirements are fulfilled, as well as to provide data which are used to manage risks and to make improvements. The sections below describe other feedback systems in place.

6.1. Control of Nonconforming Product

The Project requires the use of systems to identify and track nonconformances (NCR). NCRs which affect functional requirements or interfaces with subsystems at other collaborating institutions will be shared amongst the collaborating institutions.

[26] https://edms.cern.ch/document/1511434/

[27] https://us-hilumi-docdbcert.fnal.gov/cgi-bin/cert/ShowDocument?docid=1166

Deviation requests (i.e. when a deliverable will not meet an approved functional or interface requirement) require approval by the CERN Work Package Engineer, and will be processed via the CERN procedure *HL Deviation Process* (EDMS 1506723[28]).

Suspect/Counterfeit Items (S/CI) fall within the scope of nonconforming product, and are reported and dispositioned through the normal NCR mechanisms.

There are two nonconforming product systems in place for the Fermilab portion of the Project. One is for incoming inspections, and the other is for all other inspections. The Quality Control Reporting (QCR) system is managed by the Quality & Materials Department in the Technical Division, and is used to communicate and resolve issues related to incoming inspections. The Discrepancy Reporting (DR) system is integrated with the electronic traveler system, *Vector*, and is used to communicate, understand and resolve issues related to production or final measurements.

6.1.1. Significant NCRs

So-called "significant NCRs" are required to be communicated to the AUP project office, and then to CERN. "Significant" means the issue impacts a functional requirement, results in a schedule delay or cost variance, or is deemed to be something that the AUP project office should know about. It is recognized that this definition is qualitative, not quantitative, and so the Project is relying on strong communication between the collaborating labs and the Project Office, working from the understanding that the higher the transparency the lower the Project risk.

Significant NCRs are communicated to the AUP project office:

1. Close to "real time" (via email and/or phone). "Close" means after sufficient understanding of the problem, but generally within a matter of days after the issue is discovered. And,
2. Once per month using the Significant NCR tracking sheet, emailed to the Project QA Manager (blowers@fnal.gov). This is to be completed within the first week of each month.

Significant NCRs are communicated to the CERN Work Package Engineer from the Project Office, as per the requirements in CERN document *HL Nonconformity Process* (EDMS 1499015[29]).

According to the MQXFA Acceptance Criteria (DocDB #1103), failing to meet requirements MQXFA-R-O-01, MQXFA-R-O-02, MQXFA-R-O-03, or MQXFA-R-O-07 are defined as significant, and would trigger the HL Nonconformity Process.

6.2. Assessments (Criteria 9 & 10)

The Project requires that quality assessments be performed during the duration of the Project, using a graded approach.

In addition, the Project fulfills the requirements of the CERN procedure *HL Auditing* (EDMS 1518365[30]). As with internal assessments, all findings and action items are tracked to closure.

Additional details regarding assessments can be found in the AUP Integration Plan (DocDB #1166[31]).

[28] https://edms.cern.ch/document/1506723/
[29] https://edms.cern.ch/document/1499015/
[30] https://edms.cern.ch/document/1518365/
[31] https://us-hilumi-docdbcert.fnal.gov/cgi-bin/cert/ShowDocument?docid=1166

Along with the quality assessments, many project reviews are completed on the Project. Although reviews are not assessments, per se, they do provide a mechanism by which work planning and outcomes are reviewed and assessed for adequacy and possible improvements. All recommendations and action items from reviews are tracked to closure.

For the Fermilab portion of the work, the Project works within the Fermilab self-assessment framework, as defined in Quality Assurance Manual chapter 12080[32]. In addition, the work performed in the Applied Physics and Superconducting Technology Division falls within the scope of policy TD-2020 *Self-Assessment Program*[33], which describes the various assessments in place in the Division. These assessments are used to continually improve the operations of the Division.

7. Collaborating Institution Requirements

This plan describes the policies and procedures that the Project is adopting to assure quality and meet the customer's requirements. As an aid to the collaborating institutions, below is a list of specific topics which shall be addressed by them:

- Formal QA Plan specific to the AUP work
- System for document and data control; shall include the use of CERN's EDMS for CERN-required documents (e.g. functional and interface specifications)
- System for records management
- System for controlling designs and interfaces to other subsystems for which other institutions are the design authority; includes the uploading of design records to the CERN Drawing Directory (CDD)
- System for managing and controlling procurements
- System to maintain product ID and traceability
- System for receiving inspections
- System for in-process inspections
- Calibration of equipment
- The use of travelers or work instructions;
- The use of the CERN MTF system, including the use of Manufacturing and Inspection Plans (MIP)
- System for controlling nonconforming product; shall include S/CI
- Internal assessments
- Corrective/preventive actions system; shall include tracking review/assessment action items to closure
- Sharing of the necessary information (e.g. designs, test results, NCRs) with the other labs

[32] http://esh-docdb.fnal.gov/cgi-bin/ShowDocument?docid=2689

[33] http://www-tdserver1.fnal.gov/tdweb/hq/policies/2020.pdf